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SOUND WAVES

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1. WHAT IS SOUND?

1.1 Human beings have senses of sight, touch, hearing, taste and smell, by which we can detect events taking place about us. Each sense is associated with a particular area of the brain. For example, when light is applied to the eyes, the optical nerves transmit that stimulus to the area associated with the sensation of seeing, or sight. The stimulus which produces the sensation of hearing is called sound. When sound is applied to the ears (or to the bones of the head behind the ears), the auditory nerves transmit that stimulus to the part of the brain associated with the sensation of hearing. Fundamentally, *sound is what we hear.*

1.2 Musical and speech sounds usually originate from some form of mechanical vibration, which sets up corresponding vibrations in the air and other surrounding objects.

1.3 This paper gives us a general knowledge of the nature of sound, speech and hearing, and helps us understand Telephony, in which the relation between sound and electricity is very important.

2. HOW SOUNDS ARE TRANSMITTED.

2.1 THE TRANSMITTING MEDIUM. Sounds are usually carried or transmitted from one point to another through air, but they may be transmitted to varying degrees through any solid, liquid or gas. Unlike light and radiant heat, sound cannot be transmitted through a vacuum.

For example, Fig. 1 shows a magneto bell in the sealed glass jar connected to a vacuum pump. The sound from the bell is transmitted through the air inside the jar, through the glass walls of the jar, and then through the air outside the jar to our ears. When the air is exhausted from the jar by the operation of the pump, the sound gradually becomes fainter and finally ceases. The bell is still vibrating but there is no longer any air around it to transmit the sound. When the air is gradually admitted again, the sound returns. This experiment also shows that the loudness of the sound depends on the density of the air.

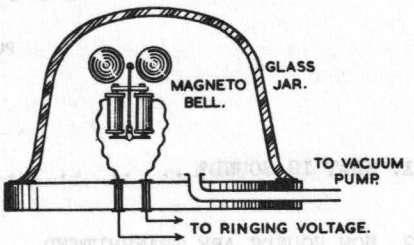


FIG. 1. SOUND NEEDS A TRANSMISSION MEDIUM.

2.2 THE TUNING FORK is a simple example to show how sound is transmitted through air. When the fork is "struck", the prongs vibrate rapidly and vary the air pressure in their immediate vicinity. This sets up, in the adjacent air particles, a series of alternate *compressions* (pressures greater than normal) and *rarefactions* (pressures less then normal) which travel outwards in all directions from the source.

For example, in Fig. 2a, the prong of the fork advances swiftly and compresses the air particles immediately in front of it. The energy of the compression is transmitted to neighbouring particles and moves outwards. The prong then recedes (Fig. 2b) and leaves behind it a rarefaction or partial vacuum. While the compression and rarefaction are being transmitted, the prong again advances (Fig. 2c) and compresses the air particles. The prong recedes again (Fig. 2d) and produces a further rarefaction.

In Fig. 2, the denser sections represent compression, and the lighter sections, rarefaction. For simplicity, only a narrow strip section is shown, but it is important to know that all the air around the prongs is similarly affected.

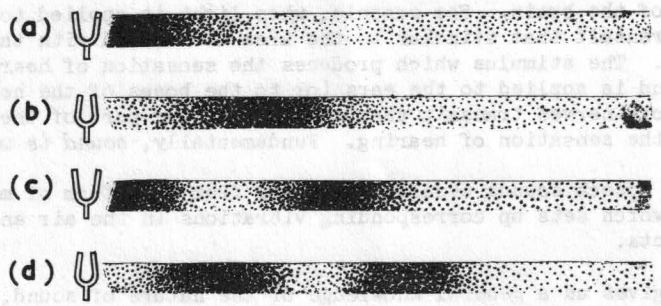


FIG. 2. TRANSMISSION OF SOUND.

2.3 MOVEMENT OF PARTICLES. Vibrating objects cause the particles of the transmitting medium to move backwards and forwards about their normal or rest positions in line with the direction in which the sound is travelling. In Fig. 2, the air particles at the immediate right-hand side of the right-hand prong move to the right at (a), to the left at (b), to the right at (c), and so on. The greater the movement of the fork prong, the greater the displacement of the individual air particles.

In practice, the distances moved are very small, ranging from much less than one millionth of a centimetre for barely audible sounds to about one thousandth of a centimetre for very loud sounds in air. The distances moved in liquids and solids are much smaller, because their molecules are spaced much closer than those of gases. This means that a molecule of a liquid or a solid does not move as far as that of a gas without colliding with some other molecule, in which collision the energy possessed by the first molecule is transferred to the second molecule.

★ **2.4 VELOCITY (OR SPEED).** Examples of the velocity of sound are seen in everyday life. Thunder always follows lightning although both occur together at the source. The crack of a bat hitting a cricket ball is often heard after the hit is seen. The sound of an explosion takes some time to reach a distant observer.

The velocity of sound depends on the nature and temperature of the transmitting medium. For example:-

- In air, sound travels at about 331 metres per second (m/s) at $0^{\circ}C$. The velocity increases (or decreases) about 0.6 m/s for every $1^{\circ}C$ rise (or fall) of temperature. Thus, the velocity is about 340 m/s at $15^{\circ}C$.
- In water, the velocity is about 1,430 m/s.
- In solids, the velocity varies from about 3,500 m/s to 5,000 m/s.

2.5 GRAPHICAL REPRESENTATION. For convenience, sound vibrations are usually drawn as graphs. For example, if the vibrations of a tuning fork prong are traced on a moving paper tape (Fig. 3a), the trace is a sine curve, that is, the graph of the sine ratio of an angle as it varies from 0° through all angles to 360°. Similarly, the varying degrees of compression or rarefaction of the air particles may be indicated by a graph drawn above or below a reference line which represents the normal air pressure (Fig. 3b).

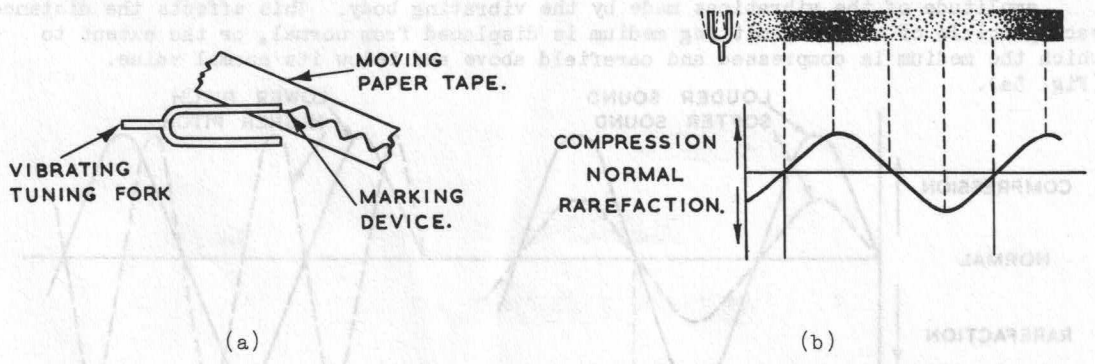


FIG. 3. GRAPH OF SOUND WAVES.

From the shape of these graphs, the term *Sound Wave* is applied to the successive compressions and rarefactions in the transmitting medium.

2.6 ATTENUATION. (Fig. 4). As the distance from the source of a sound is increased, the loudness (or amplitude of the sound wave) quickly decreases until the sound is inaudible some distance from the source. This effect is called Attenuation, and the sound is said to be attenuated as it progresses outwards from the source. The attenuation or loss of energy is caused by dispersion of the sound waves and by frictional losses in the transmitting medium.

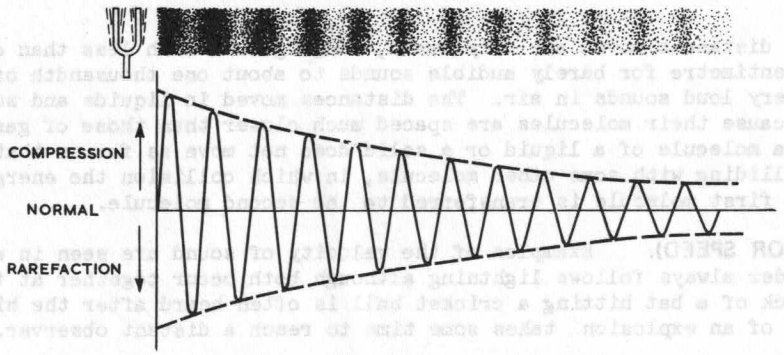


FIG. 4. ATTENUATION OF A SOUND WAVE.

2.7 REFLECTION AND ECHOES. When sound waves travelling through air strike any obstruction such as a wall, hill, etc., some of the sound continues to travel through the obstruction, and the remainder is reflected back. Thus, a person may often hear the same sound via the direct path and also the indirect or reflected paths. When heard separately from the direct sound, the reflected sounds are called echoes.

3. VOLUME, PITCH AND TIMBRE.

3.1 Sound waves have three important characteristics:-

- Volume, that is, whether the sound is loud or soft.
- Pitch, that is, whether the sound is high or low.
- Timbre, or the distinctive quality of the sound.

3.2 THE VOLUME, LOUDNESS OR INTENSITY of a sound is determined by the amplitude of the vibrations made by the vibrating body. This affects the distance each particle of the transmitting medium is displaced from normal, or the extent to which the medium is compressed and oarefield above and below its normal value. (Fig. 5a).

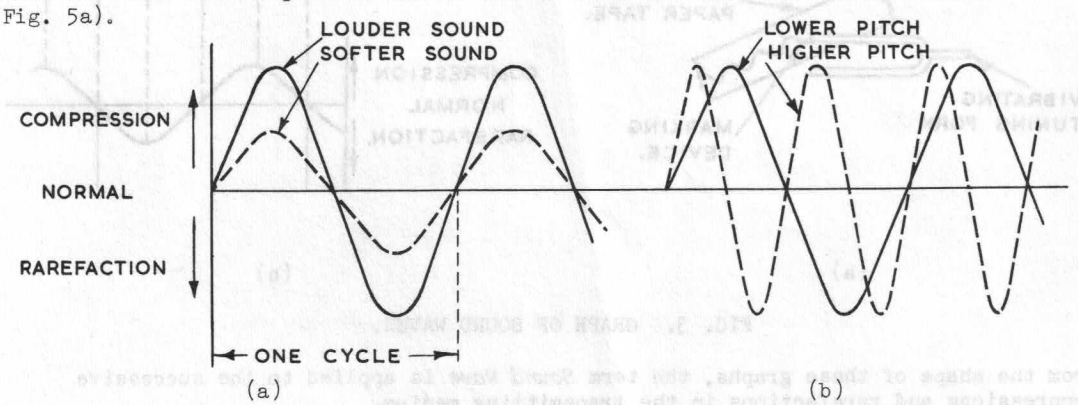


FIG. 5. SOUNDS OF DIFFERING VOLUME AND PITCH.

3.3 THE PITCH of a sound is determined by the number of vibrations per second made by the vibrating body, and, therefore, by the number of complete waves per second transmitted by that body.

For example, Fig. 5a compares the graphs of sounds of differing volume but the same pitch; and Fig. 5b compares sounds of the same volume but of differing pitch (or frequency).

★ **3.4** Referring to Fig. 5:-

A *cycle* is the term given to one complete wave of compression and rarefaction.

The *frequency* of the sound is the number of cycles produced each second. Increasing the number of vibrations increases the frequency and raises the pitch. In Fig. 5b, the higher pitch sound is twice the frequency of the lower pitch sound. Frequencies are measured in terms of a unit called the *hertz* (abbreviated to Hz), which is equivalent to the number of cycles per second.

The *period* is the time taken for one cycle. Thus, for a frequency of 1000 Hz,

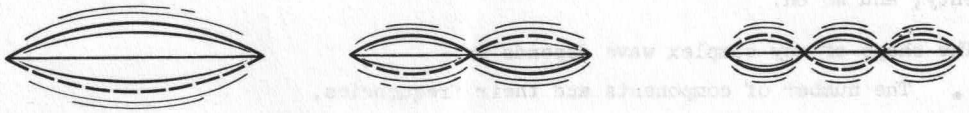
$$\textit{the period} = \frac{1}{1{,}000}\ \textit{second.}$$

The *wavelength*, usually denoted by the Greek letter λ (Lambda), is the distance occupied by one complete cycle; it can be expressed in any unit of length. Thus, for a frequency of 1,000 Hz the wavelength in air (at 15°C):-

$$\lambda = \frac{\textit{velocity}}{\textit{frequency}} = \frac{340\ m/s}{1{,}000\ Hz} = 0.34\ \textit{metre}$$

3.5 QUALITY OR TIMBRE (a French word meaning "tone colour") is that characteristic which distinguishes sounds of the same pitch and volume.

The reason for differences in quality is seen from a long string or wire which is stretched tight and then plucked with the finger (Fig. 6). When it vibrates as a whole, the wire produces its *fundamental* note. But when touched in the middle while vibrating, either section vibrates twice as fast and the higher pitched note is called an overtone or *harmonic*. When the string vibrates in two parts, it produces a second harmonic; in three parts, a third harmonic; and so on.



(a) Fundamental. (c) 2nd Harmonic. (c) 3rd Harmonic.

FIG. 6. PRODUCTION OF TONES BY VIBRATING STRINGS.

A vibrating object may produce a fundamental note and harmonics simultaneously. The fundamental frequency determines the pitch of the sound, and is the same for different musical instruments playing the same note. The harmonics, when added to the fundamental, vary the quality of the sound. For example, we can distinguish between different musical instruments playing the same fundamental note because the number and the relative strengths of the harmonics produced by each, are different.

4. ANALYSIS OF SOUND WAVEFORMS.

4.1 Sound waves can be divided into two types:-

- Sine waves, which are the simplest form, and are referred to as a pure sound.
- Non-sinusoidal or complex waves.

Very few sounds have the pure sine wave formation of a tuning fork vibration. Some typical waveforms are shown in Fig. 7. Although the complex waveforms are not sinusoidal, they are regular, that is, each curve is repeated again and again. The difference between a musical note and a noise is that the musical note contains a repetition of a waveform but a noise has no recurring waveform.

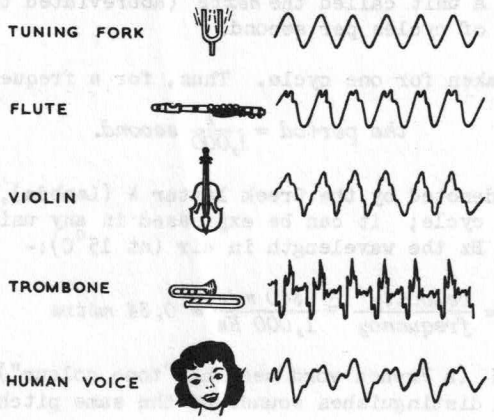


FIG. 7. SOME TYPICAL WAVEFORMS.

4.2 All recurring complex waves are made up of two or more sine waves of different frequencies. The lowest frequency is the *fundamental frequency*, and this is the frequency of the complex wave. The other sine wave components are *harmonic frequencies*, because their frequencies are multiples or harmonics of the fundamental. The multiple which is twice the fundamental frequency is called the second harmonic frequency, and so on.

4.3 The shape of any complex wave depends on:-

- The number of components and their frequencies.
- The relative amplitudes of the components, and
- The phase relationship between the components.

For example, in Fig. 8, the fundamental frequency (and, therefore, the pitch of the sound) is the same in each case, but the resultant waveform (and, therefore, the quality of the sound) is varied by harmonics of different frequency, amplitude, and phase relationship.

Fig. 8a shows a complex wave composed of a fundamental and second harmonic.

Fig. 8b shows the resultant waveform when a third harmonic is added to the same fundamental.

Fig. 8c shows the effect when the amplitude of the harmonic frequency is reduced.

Fig. 8d shows the effect of varying the phase relationship between the components. For example, comparing Fig. 8d with Fig. 8c, the position of the second harmonic has been shifted (or varied in phase) with respect to the fundamental.

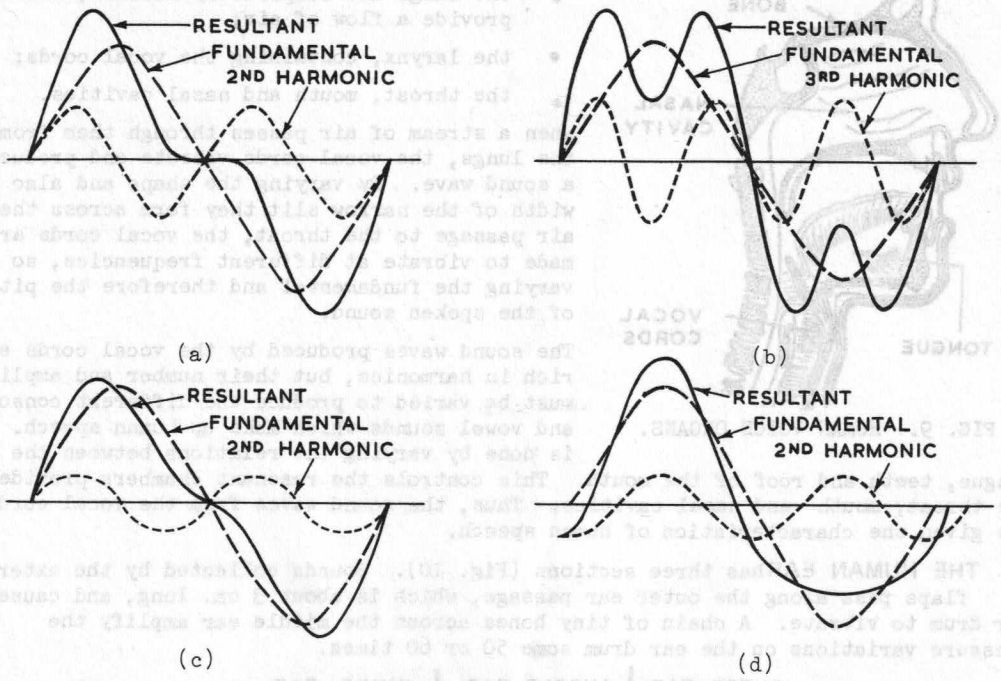


FIG. 8. ANALYSIS OF COMPLEX WAVES.

4.4 DISTORTION. Any change (other than in overall amplitude due to, perhaps, attenuation) in the shape of the original sound waveform as it passes from one point to another, is called distortion.

Distortion affects the quality of the received sound and may be caused by any alteration in the three factors which affect the waveform. In extreme cases of distortion, the received sound may be quite unintelligible.

4.5 RESONANT FREQUENCY. When a tuning fork is struck, it immediately vibrates at the particular frequency for which it has been designed. This is called the natural or resonant frequency of the fork.

If the fork prongs are at rest and placed in the path of a sound wave which has the same frequency as the resonant frequency of the fork, the prongs will vibrate at this frequency. The fork will not vibrate at other frequencies except when the amplitude of the sound wave applied to it is very large, and then only slightly, unless perhaps the sound is exactly half or twice the resonant frequency of the fork.

Similarly, all objects, including enclosed volumes of air, have natural or resonant frequencies at which they vibrate most readily. The resonant frequency of such objects as transmitter and receiver diaphragms, etc., must be considered in the operation of telephone apparatus.

When any object continues to vibrate of its own accord for some considerable time after the energising souce has been removed, the emitted sound wave is said to be *undamped*, but when the amplitude of vibration is quickly reduced, generally by mechanical means, the sound wave is *damped*.

5. SPEECH AND HEARING.

5.1 THE HUMAN VOCAL ORGANS (Fig. 9) consist of:-

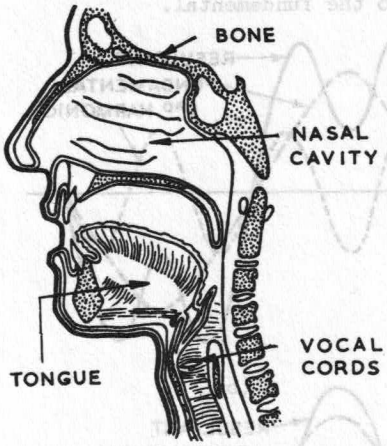


FIG. 9. HUMAN VOICE ORGANS.

- the lungs and respiratory muscles, which provide a flow of air;
- the larynx, containing the vocal cords;
- the throat, mouth and nasal cavities.

When a stream of air passes through them from the lungs, the vocal cords vibrate and produce a sound wave. By varying the shape and also the width of the narrow slit they form across the air passage to the throat, the vocal cords are made to vibrate at different frequencies, so varying the fundamental and therefore the pitch of the spoken sound.

The sound waves produced by the vocal cords are rich in harmonics, but their number and amplitude must be varied to produce the different consonant and vowel sounds which make up human speech. This is done by varying the relations between the lips, tongue, teeth and roof of the mouth. This controls the resonant chambers provided by the throat, mouth and nasal cavities. Thus, the sound waves from the vocal cords are given the characteristics of human speech.

5.2 THE HUMAN EAR has three sections (Fig. 10). Sounds collected by the external flaps pass along the outer ear passage, which is about 3 cm. long, and cause the ear drum to vibrate. A chain of tiny bones across the middle ear amplify the pressure variations on the ear drum some 50 or 60 times.

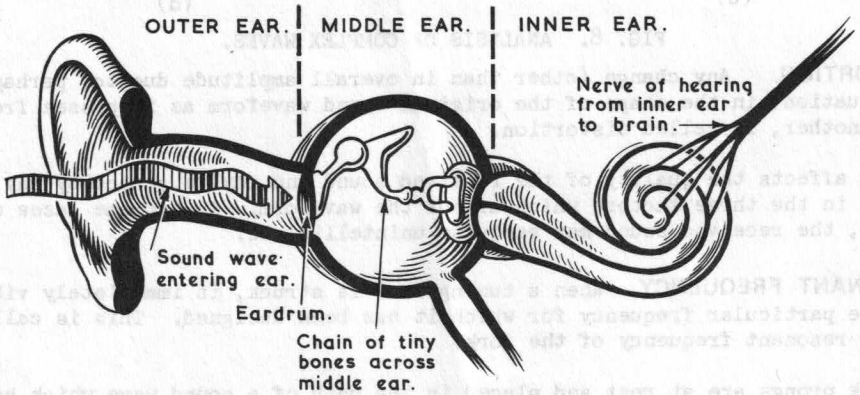


FIG. 10. HUMAN EAR.

The inner ear contains a spiral tube filled with a fluid in which are thousands of nerve ends, each of which is resonant to a particular small range of frequencies and is stimulated only when those frequencies are received. The nerve ends send pulses along the auditory nerve to the brain to give the sensation of hearing. The ear is sensitive not only to differences of frequency but also to differences in loudness, which cover a power ratio of more than one million to one.

★**5.3 AUDIO FREQUENCY (A.F.) RANGE.** Audio frequencies are those which may be heard by the ear when the energy is in the form of sound waves. The A.F. range is from about 16 Hz to 20,000 Hz, but the limits vary with different persons. Most people can hear from 30 Hz to 15,000 Hz. The sound from an orchestra may cover most of the A.F. range (fundamentals and harmonics) but the range used for speech is very much less. The sensitiveness of the ear varies over the A.F. range. It is a maximum at about 2,000 Hz and decreases as the upper and lower limits of audibility are approached.

6. ELECTRICAL TRANSMISSION OF SOUND.

6.1 Sound is a form of energy sometimes called acoustical energy, from the Greek word akoustikos meaning to hear. Sound waves cannot be transmitted very far because they have comparatively small energy and attenuate rapidly. They must first be changed to another form of energy that does not attenuate so rapidly and can be transmitted more easily from one point to another.

6.2 The subject of Telephony deals with the electrical transmission of sound (speech and music) between points some distance apart. The word is derived from two Greek words - tele meaning far, and phone meaning voice. Telephony is one of the modern forms of communication, and the messages may be sent over either line wires or radio channels.

A telephone is a device which converts the energy of sound waves in speech to electrical energy when transmitting, and electrical energy back into sound when receiving.

A practical telephone must also provide a means of signalling at both ends of the line preparatory to speaking, and a means of receiving such signals. The basic requirements are, therefore, transmitting, receiving and signalling.

6.3 Although many interesting experiments had been done previously, the first practical telephone was developed in 1876-77 when Alexander Graham Bell demonstrated that sound waves in the air could be recreated some distance away by means of alternating currents sent over wires. (Fig. 11).

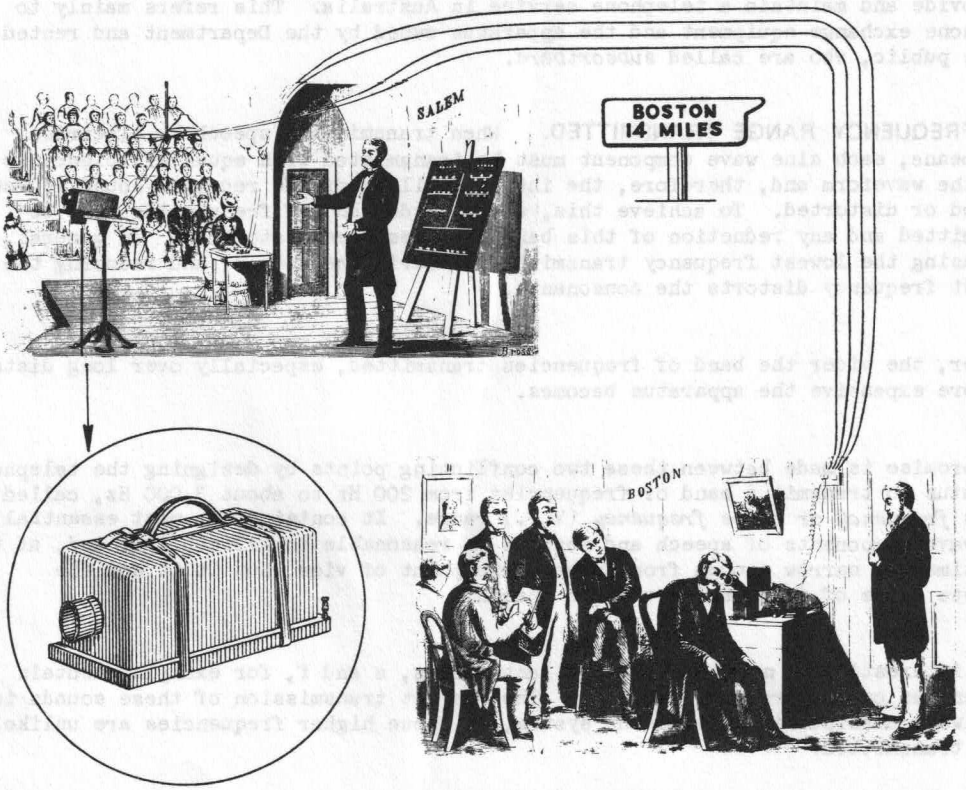


FIG. 11. THE TELEPHONE IN 1877.

★ The telephone was introduced in Australia in 1878. Since then, many different types have been used and, for identification, a numeral code has been adopted. The telephones most commonly used at present are in the 400 and the 800 series.

The original telephones were largely experimental but, as improvements were made, the provision of a comprehensive telephone service within and between communities soon became a practical possibility. A telephone service within a community area, for example a town, suburb, or city, is provided by terminating all the lines from the telephones in that area at a central building called a *telephone exchange*, where any two lines and their corresponding telephones can be connected together, as required.

The source of the electric energy may be either a local battery at the telephone (Magneto working) or a central battery at the exchange (C.B. working). There are two types of C.B. exchange - manual and automatic - and, therefore, two types of C.B. telephone - manual and automatic - which differ only in the method of signalling from the telephone. By usage, however, the telephones are known as C.B. and automatic respectively, but it should be remembered that both are central battery instruments.

These telephones and the different exchange systems are described in other Technical Publications.

One function of the Engineering Division of the Postmaster-General's Department is to provide and maintain a telephone service in Australia. This refers mainly to telephone exchange equipment and the apparatus owned by the Department and rented to the public, who are called *subscribers*.

★ **6.4 FREQUENCY RANGE TRANSMITTED.** When transmitting speech by electrical means, each sine wave component must be transmitted with equal efficiency so that the waveform and, therefore, the intelligibility of the received sound is not changed or distorted. To achieve this, a very wide band of frequencies must be transmitted and any reduction of this band produces some distortion. In general, increasing the lowest frequency transmitted distorts the vowels, and reducing the highest frequency distorts the consonants.

However, the wider the band of frequencies transmitted, especially over long distances, the more expensive the apparatus becomes.

A compromise is made between these two conflicting points by designing the telephone apparatus to transmit a band of frequencies from 200 Hz to about 3,000 Hz, called the *speech frequency* or *voice frequency* (V.F.) range. It contains the most essential sine wave components of speech and results in reasonable intelligibility and, at the same time, is narrow enough from an economic point of view, but it is not the complete range of frequencies used in speech.

It is interesting to note that the sibilant sounds, s and f, for example, contain frequencies of the order of 4,000 Hz. The correct transmission of these sounds is not always possible in a telephone system, as these higher frequencies are unlikely to be transmitted.

For good quality music, a range from about 30 Hz to 10,000 Hz is generally transmitted.

NOTES

7. TEST QUESTIONS.

1. *Can sounds be transmitted through a vacuum? .....*
2. *Describe a simple experiment to support your answer in Question 1.*
3. *Explain how sounds are transmitted through air.*
4. *The term "Sound Wave" is applied to .....*
5. *What is meant by "attenuation," applied to sound waves?*
6. *How are "echoes" produced?*
7. *Three important characteristics of a sound wave, are:-*

   (1) .....

   (2) .....

   (3) .....
8. *What is meant by the terms - cycle, frequency, period, wavelength?*
9. *The relationship between velocity, wavelength and frequency of a sound wave is .....*
10. *A complex wave consists of ..... and ..... frequencies.*
11. *The ..... frequency determines the pitch of the sound.*
12. *The ..... frequencies vary the quality of the sound.*
13. *The shape of any complex wave depends on:-*

    (1) .....

    (2) .....

    (3) .....
14. *What is meant by the resonant frequency of an object?*
15. *What is the main difference in the waveforms of a musical note and noise?*
16. *The A.F. range extends from about ..... Hz to ..... Hz.*
17. *Why is it necessary to convert acoustical energy to electrical energy for transmission over long distances?*
18. *What is the frequency range usually used for telephone transmission of speech? ..... This is called the ..... range.*

END OF PAPER.

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